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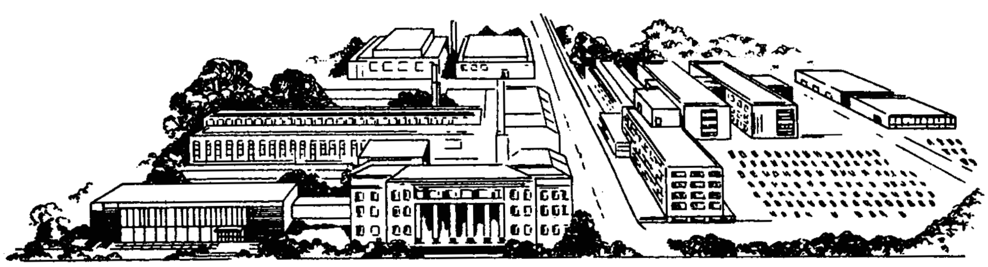

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FIFTH QUARTERLY REPORT

on

A STUDY OF THE RELIABILITY OF ELECTRONIC COMPONENTS IN A NUCLEAR-RADIATION ENVIRONMENT

to

JET PROPULSION LABORATORY

April 1, 1964

by

C. L. Hanks, D. J. Hamman, and E. N. Wyler

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

BATTELLE MEMORIAL INSTITUTE
505 King Avenue
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Battelle Memorial Institute

505 KING AVENUE COLUMBUS, OHIO 43201

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April 13, 1964

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California

Attention Mr. J. Michael Whalen
Contract Negotiator

Gentlemen:

This is the Fifth Quarterly Report and Sixteenth Monthly Progress Report on Contract No. 950458 (File 2998) entitled "A Study of the Reliability of Electronic Components in a Nuclear-Radiation Environment". The period covered is from January 1 to March 31, 1964.

Progress during this report interval has included the completion of a preliminary analysis of the results from the 100-hour irradiation of the component parts in the 100 C, high-flux capsule (Test Group IV). Effort has also included the performance of post-irradiation measurements at room ambient on the parts in this capsule as well as initial or preirradiation measurements on the component parts in Test Groups I, II, and V. Measurements on the parts in Test Group III were delayed when a water leak was discovered on the atmospheric side of the vacuum feedthrough plate of the capsule. The water resulted in corrosion, short circuits, and grounds in the connectors and vacuum electrical feedthroughs which have since been cleaned, dried, and returned to normal operating condition.

Project effort has also included analysis of the results from the 1000-hour gamma irradiation of the CL605 cadmium sulfide cells at an exposure rate of $1.04 \pm 0.08 \times 10^6$ ergs g^{-1} (C) hr^{-1}.

Very truly yours,

E. N. Wyler
Project Director
Environmental Effects

ENW:eh
Enc.

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A STUDY OF THE RELIABILITY OF
ELECTRONIC COMPONENTS IN A NUCLEAR-
RADIATION ENVIRONMENT

by

C. L. Hanks, D. J. Hamman, and E. N. Wyler

INTRODUCTION

This is the Fifth Quarterly Report and the Sixteenth Monthly Progress Report on Contract No. 950458 (File 2998) entitled "A Study of the Reliability of Electronic Components in a Nuclear-Radiation Environment". This report summarizes the project activity from January 1 to March 31, 1964, which has included the completion of the dosimetry analysis for the 100-hour irradiation of the component parts in the 100 C, high-flux capsule and a preliminary analysis of the test results that were obtained. The analysis of the results from the 1000-hour gamma irradiation of the CL605 cadmium sulfide cells was also completed.

PROGRESS SUMMARY

Progress during this report interval has included the following project activities:

(1) Completion of a preliminary analysis of the results from the 100-hour irradiation of the high-flux capsule (Test Group IV)

(2) Completion of the analysis of the test results obtained from the 1000-hour gamma irradiation of the cadmium sulfide cells

(3) Performance of postirradiation measurements at room ambient on component parts in the 100 C, high-flux capsule (Test Group IV)

(4) Performance of initial or preirradiation measurements on component parts in Test Groups I, II, and V.

TECHNICAL DETAILS

Project effort during this report interim was directed toward the performance of postirradiation measurements at room ambient on component parts in the 100-hour, high-flux capsule, and the performance of initial measurements at room ambient on component parts in the two control test chambers, i.e., Test Groups I and II, and the two 10,000-hour low-flux capsules, i.e., Test Groups III and V. In addition, the dosimetry analysis of the radiation exposure and a preliminary analysis of the test results were complete for the 100-hour, high-flux irradiation of the component parts in Test Group IV. The results from the 1000-hour gamma irradiation of the Type CL605 cadmium sulfide cells were also analyzed during this interval.

This section presents various details concerning these activities and the progress that has been made.

100 C, High-Flux Capsule, Test Group IV

A preliminary analysis of the test results and the dosimetry analysis of the radiation exposure were completed for the 100-hour, high-flux capsule, which was irradiated during the latter part of the previous report interim. Postirradiation measurements at room ambient have been completed with the exception of measurements on the five capacitor types, the 2N2297 transistors, and four diode types (FD1184, 1N2063, 1N822, and PS4653).

Preliminary Analysis

The results from the preliminary analysis of the data obtained from the irradiation of component parts in the 100-hour, high-flux capsule are shown in Table 1. The information presented includes the minimum and maximum values of the various parameters measured on each part type for each of three measurement intervals, i.e., 25 C preirradiation, 100 C preirradiation, and 100 C postirradiation.

Exposure to a combined environment of elevated temperature (100 C), vacuum (10^{-5} torr or less), and nuclear radiation (3×10^{7} n cm^{2} sec^{-1} and 1×10^{7} ergs g^{-1}(C) hr^{-1}) for 100 hours had little or no effect on the component parts other than the semiconductor devices. In actuality, the insulation resistance measurements showed improvement, which may be attributed to the removal or reduction of surface leakage possibly due to the combined effects of elevated temperature and vacuum. The only definite indication of degradation for parts other than the semiconductor devices was an increase in the leakage current of one Aerovox P323ZN capacitor, which increased from 0.2184 microampere for the 100 C preirradiation measurement to 28.0 microamperes for the 100 C postirradiation measurement. In general, the leakage current of all capacitor types showed an increase between the 25 C and 100 C preirradiation measurements and a decrease between the 100 C pre- and postirradiation measurements.

Resistance measurements on the three resistor types indicate a slight decrease with temperature but little or no change from the radiation exposure.

Data from the measurements of the voltage-to-close for the Sigma 32RJD90GD indicate a slight increase with temperature and after the exposure to radiation.

The radiation exposure had a somewhat pronounced effect on all of the semiconductor diodes as shown in Table 1. Results on the FD 1184 diodes indicate that one unit is open or approaching an open-circuit condition, 10 units show a marked decrease in forward voltage drop (V_F) while others show an increase, and all 20 units increased in reverse leakage current.

TABLE 1. PARAMETER RANGE VALUES FROM THE 100-HOUR, HIGH-FLUX RADIATION STUDY

		Parameter Range at the Indicated Measurement Interval					
		25 C Preirradiation		100 C Preirradiation		100 C Postirradiation	
Component Description	Parameter Identity	Min	Max	Min	Max	Min	Max
Capacitors							
Aerovox, P323ZN	Capacitance, µf	0.900	1.020	0.930	1.070	0.930	1.070
	Dissipation Factor, %	0.15	0.22	0.14	0.25	0.16	0.21
	Leakage Current, µA	1.024	1.303	2.045	2.859	0.3749	28.0
Sprague, 118P	Capacitance, µf	1.035	1.080	1.040	1.080	1.030	1.080
	Dissipation Factor, %	0.14	0.22	0.17	0.22	0.15	0.19
	Leakage Current, µA	0.8828	1.361	1.945	3.365	0.4370	0.8559
Good-All, 683G	Capacitance, µf	0.960	1.030	0.980	1.050	0.970	1.040
	Dissipation Factor, %	0.09	0.23	0.15	0.21	0.11	0.17
	Leakage Current, µA	0.0407	0.0535	0.1899	0.2184	0.0223	0.0595
General Electric, 29 F	Capacitance, µf	2.100	2.170	2.160	2.230	2.080	2.170
	Dissipation Factor, %	0.80	1.10	0.63	0.98	0.99	2.19
	Leakage Current, µA	0.1549	0.2724	0.6670	1.544	0.0167	0.1643
Fansteel, HP	Capacitance, µf	50.80	59.60	51.90	60.80	51.70	59.20
	Dissipation Factor, %	4.94	6.06	4.74	5.60	4.96	6.80
	Leakage Current, µA	0.2361	0.5397	0.4344	2.745	0.0902	0.5947
Resistors							
Texas Inst., CG	Resistance, K-ohms	98.69	100.0	97.19	98.84	98.43	98.89
Corning Glass, C-07	Resistance, K-ohms	98.39	100.9	98.14	100.3	98.65	100.7
Allen-Bradley, CB	Resistance, K-ohms	96.76	98.89	94.17	96.89	94.32	97.40
Potentiometer							
New England Inst., 78P	Resistance, K-ohms	16.99	20.49	17.07	21.61	16.97	20.88
	Insulation Resistance, M-ohms	145.3	159.1	199.6	240.85	304.41	321.75
Relay							
Sigma, 32RJD90GD	Voltage to Close, volts	1.910	2.919	2.333	3.252	2.352	3.419
	Insulation Resistance, M-ohms	156.74	179.05	234.2	262.2	297.2	341.8

TABLE 1. (Continued)

Component Description	Parameter Identity	Parameter Range at the Indicated Measurement Interval					
		25 C Preirradiation		100 C Preirradiation		100 C Postirradiation	
		Min	Max	Min	Max	Min	Max
Switch							
Minneapolis-Honeywell, 1HM1	Open-Position Resistance, M-ohms	216.3	231.3	276.9	293.3	369.2	397.8
Transformer							
Triad, SP-13	Excitation Current, mA	0.2383	1.067	0.3434	1.289	0.2769	1.170
	Insulation Resistance, M-ohms	79.90	106.5	162.6	240.1	1115.4	1564.9
Connectors							
Bendix, PT00A8	Insulation Resistance						
	Pin to Case, M-ohms	151.5	155.6	281.2	283.2	338.4	939.8
	Pin to Pin, M-ohms	128.3	130.7	149.4	152.0	256.3	440.4
Cinch, DEM-9	Insulation Resistance						
	Pin to Case, M-ohms	869.9	962.0	291.3	294.9	1117.9	1221.0
	Pin to Pin, M-ohms	157.6	237.5	150.6	153.1	447.5	478.8
Diodes							
Fairchild, FD1184	Forward Voltage Drop at 5 mA, volts	0.6819	0.7273	0.5690	0.6186	0.1064	295.7[a]
	Forward Voltage Drop at 30 mA, volts	0.8949	1.030	--	--	--	--
	Forward Voltage Drop at 0.1 mA, volts	0.4764	0.4923	--	--	--	--
	Reverse Current at 50 Vdc, μA	0.0810	0.1090	1.001	56.33	7.804[a]	499.0
Fairchild, FD643	Forward Voltage Drop at 100 mA, volts	1.079	1.149	0.9921	1.066	0.2506	38.33
	Forward Voltage Drop at 400 mA, volts	1.954	2.129	--	--	--	--
	Forward Voltage Drop at 0.1 mA, volts	0.4771	0.5039	--	--	--	--
	Reverse Current at 60 Vdc, μA	0.1044	0.1296	1.102	1.649	9.299	58.09 mA
Texas Inst., 1N916	Forward Voltage Drop at 1.0 mA, volts	0.5683	0.6049	0.4433	0.4847	0.3854	0.8421
	Forward Voltage Drop at 10 mA, volts	0.7223	0.8231	--	--	--	--
	Forward Voltage Drop at 0.1 mA, volts	0.4604	0.4935	--	--	--	--
	Reverse Current at 20 Vdc, μA	0.0326	0.0452	0.2955	0.7566	0.0099	19.95 mA
International Rectifier, 1N2063	Reverse Current at 200 Vdc, mA	0.1764	7.956	0.5016	7.788	1.982	8.502

TABLE 1. (Continued)

Component Description	Parameter Identity	25 C Preirradiation Min	25 C Preirradiation Max	100 C Preirradiation Min	100 C Preirradiation Max	100 C Postirradiation Min	100 C Postirradiation Max
Hoffman, 1N822	Reverse Voltage at 7.5 mA, volts	6.089	6.404	6.087	6.425	6.055	6.406[b]
	Zener Impedance at 7.5 mAdc, ohms	9.259	14.68	10.09	20.57	305.9	404.9
	Zener Impedance at 1.0 mAdc, ohms	585.5	1535.0	872.9	1561.0	1039.0	2789.0
Pacific Semiconductor, PS4653	Reference Voltage at 20 mA, volts	7.831	8.366	8.089	8.656	8.139	8.771
	Zener Impedance at 20 mAdc, ohms	1.862	4.656	2.119	5.019	2.492	6.049
	Zener Impedance at 1.0 mAdc, ohms	1335.0	1587.0	1096.0	1333.0	2583.0	2630.0
Controlled Switch							
General Electric, 3N58	Forward Voltage Drop at 50 mA, volts	1.210	1.489	1.173	1.506	1.629	35.48
	Gate Voltage to Fire, volts	0.860	1.170[c]	0.560	0.910	0.640	1.280[d]
	Breakover Voltage, volts	43.00	>80.00	44.00	>80.00	48.00	>80.00[e]
	Holding Current, mA	0.1900	1.220	0.0190	0.1020	0.430	2.100[f]
Transistors							
Fairchild, 2N911	$V_{CE(SAT)}$, I_C = 10 mA, I_B = 1 mA, volts	0.1442	0.2472	0.1808	0.3519	0.3979	1.537
	I_{CBO}, V_{CB} = 75 Vdc, μA	0.0379	0.0517	0.0439	15.73 mA	0.1080	26.29
	h_{FE}, V_{CE} = 10 V, I_C = 10 mA	42	105	50	167	1(51)[g]	460[j]
	h_{FE}, V_{CE} = 10 V, I_C = 100 mA	41	71	43	99	1(7.4)[h]	84
Fairchild, 2N914	$V_{CE(SAT)}$, I_C = 200 mA, I_B = 20 mA, volts	0.3902	0.5499	0.5661	0.9096	0.4921	1.319
	I_{CBO}, V_{CB} = 20 Vdc, μA	0.0213	0.0274	0.2069	2.80[k]	53.48	19.91 mA
	I_{EBO}, V_{EB} = 4 Vdc, μA	0.0161	0.0733	--	--	--	--
	h_{FE}, V_{CE} = 5 V, I_C = 100 mA	17	33	19	41[k]	1(37)[g]	68
	h_{FE}, V_{CE} = 1 V, I_C = 10 mA	28	67	39	84[k]	1(48)[g]	88
Fairchild, 2N915	$V_{CE(SAT)}$, I_C = 10 mA, I_B = 1 mA, volts	0.3383	0.8424	0.3979	1.144	1.464	6.394
	I_{CBO}, V_{CB} = 15 Vdc, μA	0.0112	0.0147	0.0081	47.64	30.62	44.90
	h_{FE}, V_{CE} = 5 V, I_C = 10 mA	59	303[j]	209[j]	3448[j]	18	116
	h_{FE}, V_{CE} = 1 V, I_C = 10 mA	7	16	4	13	1(1.3)[l]	3.1
	h_{FE}, V_{CE} = 10 V, I_C = 100 mA	2.9	3.7	2.8	3.6	Not measurable	
Fairchild, 2N1132	$V_{CE(SAT)}$, I_C = 150 mA, I_B = 15 mA, volts	1.001	1.458	1.252	2.256	2.050	2.940
	I_{CBO}, V_{CB} = 30 Vdc, μA	0.0475	0.3689	3.499	6.480	6.872	30.49

TABLE 1. (Continued)

Component Description	Parameter Identity	Parameter Range at the Indicated Measurement Interval: 25 C Preirradiation Min	25 C Preirradiation Max	100 C Preirradiation Min	100 C Preirradiation Max	100 C Postirradiation Min	100 C Postirradiation Max
Fairchild, 2N2297	h_{FE}, V_{CE} = 10 V, I_C = 150 mA	21	40	26	51	32	90
	h_{FE}, V_{CE} = 10 V, I_C = 10 mA	32	208(j)	43	917(j)	57	4762(j, m)
	$V_{CE(SAT)}$, I_C = 150 mA, I_B = 15 mA, volts	0.1904	0.2152	0.2109	0.2439	0.3711	0.4431
	I_{CBO}, V_{CB} = 60 Vdc, µA	0.0159	0.0400	0.0249	464.8	16.00	115.7
	I_{EBO}, V_{EB} = 5.0 Vdc, µA	0.0131	0.0155	--	--	--	--
	h_{FE}, V_{CE} = 10 V, I_C = 150 mA	28	67	31	209(j)	63	134
	h_{FE}, V = 10 V, I = 10 mA	24	119	32	461(j)	99	1538(j, n)
Texas Inst., 2N930	$V_{CE(SAT)}$, I_C = 10 mA, I_B = 0.5 mA, volts	0.2292	0.6169	0.3971	1.263	1.252	3.779
	I_{EBO}, V_{EB} = 5.0 Vdc, µA	0.0009	0.0165	0.0121	0.0156	0.0420	1.019
	I_{CES}, V_{CE} = 45 Vdc, µA	0.0250	0.0365	--	--	--	--
	h_{FE}, V_{CE} = 10 V, I_C = 100 mA	5	99	3	15	3.9	3.9(n)
Texas Inst., 2N1050	$V_{CE(SAT)}$, I_C = 500 mA, I_B = 100 mA, volts	2.036	6.789	3.169	7.871	8.749	15.17
	I_{CBO}, V_{CB} = 30 Vdc, µA	0.0158	16.39	0.2110	16.91 mA	15.69	18.82 mA
	I_{EBO}, V_{EB} = 6 Vdc, µA	0.0236	5.631	--	--	--	--
	h_{FE}, V_{CE} = 10 V, I_C = 500 mA	24	48	1(19)(p)	56	Not measurable	
	h_{FE}, V_{CE} = 10 V, I_C = 10 mA	11	22	4.8(17)(p)	64	3.4	11
	h_{FE}, V_{CE} = 10 V, I_C = 100 mA	3	44	1.4(30)(p)	61	6.2	16(q)
Texas Inst., 2N2412	$V_{CE(SAT)}$, I_C = 10 mA, I_B = 1 mA, volt	0.0889	0.1269	0.1095	0.1518	0.2755	0.3324
	I_{EBO}, V_{EB} = 5 Vdc, µA	0.0046	0.0109	0.0094	0.0135	0.0008	47.80
	I_{CES}, V_{CE} = 25 Vdc, µA	0.0540	0.0875	--	--	--	--
	h_{FE}, V_{CE} = 10 V, I_C = 10 mA	56	500(j)	49	775(j)	--	236(j, r)
Philco, 2N861	$V_{CE(SAT)}$, I_C = 5 mA, I_B = 0.5 mA, volt	0.0629	0.0941	0.0122	0.1079	0.1681	0.2725
	I_{CBO}, V_{CB} = 10 Vdc, µA	0.0036	0.0496	0.0079	0.1745	0.0169	14.77
	h_{FE}, V_{CE} = 10 V, I_C = 10 mA	42	323(j)	47	347(j)	1(23)(s)	65
	h_{FE}, V_{CE} = 1 V, I_C = 10 mA	18	60	23	45	1(12)(t)	25
	h_{FE}, V_{CE} = 10 V, I_C = 100 mA	10	25	10	28	1(8.1)(t)	21

Footnotes appear on following page.

Footnotes for Table 1:

(a) Readings from same unit (No. 69) appear to be approaching an open circuit.
(b) One unit (No. 66) indicates open circuit, deleted from parameter range.
(c) One unit (No. 78) failed to fire.
(d) Four units (72, 73, 76, and 77) only units operating; Units 74 and 75 in fired condition at all times; other units would not fire.
(e) Two units that would not fire deleted from parameter range.
(f) Parameter range limited to the four units that are still operating.
(g) Value in parentheses was obtained by deleting data on two units.
(h) Value in parentheses was obtained by deleting data on two units, one of which was beyond the capability of the instrumentation.
(j) Several units appeared to be oscillating, resulting in erroneous high values.
(k) Two units (60 and 64) indicated high I_{CBO} readings and were beyond the h_{FE} instrumentations capability.
(l) Value in parentheses was obtained by deleting data on six units.
(m) Seven units beyond the capability of the instrumentation.
(n) Only two units within the capabilities of the instrumentation.
(p) Value in parentheses was obtained by deleting data on one unit which was beyond the capability of the instrumentation for the third bias condition.
(q) Same unit as in (p) above still was beyond the capability of the instrumentation.
(r) Only one unit was within the capabilities of the instrumentation.
(s) Value in parentheses was obtained by deleting data on three units.
(t) Value in parentheses was obtained by deleting data on four units.

Results from the radiation exposure of the FD 643 diodes show a marked increase in forward voltage drop for five units and a pronounced decrease in two others. Thirteen units displayed little or no change in forward voltage drop. The reverse leakage current of the FD 643 diodes in general increased by approximately one order of magnitude, with three units increasing by two or more. Two of the latter had reverse leakage currents of 58 microamperes.

Radiation exposure produced a marked increase in the reverse leakage current of eight of the Texas Instruments Type 1N916 diodes, while three others showed a decrease and nine increased slightly. The forward voltage drop on two units decreased by less than 0.1 volt, while the others increased by approximately 0.3 volt.

Measurements on the International Rectifier Type 1N2063 are limited to the reverse leakage current which increased three to ten times for three of the five units and decreased slightly for the other two when subjected to the radiation exposure.

Results on the Hoffman 1N822 reference diodes show pronounced increases in Zener impedance following exposure to radiation but only minor changes in reference voltage. In addition, measurements on one unit indicate an open circuit.

Data on the PS4653 reference diode manufactured by Pacific Semiconductors indicate little change in parameter values with the exception of Zener impedance at 1.0 mAdc and 0.1 mAac which approximately doubled with exposure to radiation.

Results on the General Electric 3N58 controlled switch indicate that only four of the 20 units tested are operating after exposure to the radiation environment. Of the remaining units, two would not fire and 14 were in a fired or conducting condition at all times.

Data presented in Table 1 on the transistor results show a definite degradation in the electrical characteristics of the nine transistor types included in this program. However, there is some question as to the validity or accuracy of the h_{FE} and I_{CBO} results. The h_{FE} measurements indicate the possibility of the transistors oscillating in spite of measures that were taken to prevent this earlier in the program when three small (0.001 μf) capacitors were connected between each combination of the three transistor leads on each transistor (with the exception of the 2N1050 which has 100-ohm resistors in series with the base lead). A possible malfunction in the instrumentation was also considered, but further investigation indicated that it was functioning properly.

The possibility of the I_{CBO} results being erroneous was also investigated when it was discovered that pickup on the emitter leads was causing high readings. This problem was corrected or eliminated by providing an a-c ground for the emitter through a 5.0-μf capacitor during I_{CBO} measurements. The I_{CBO} results on transistors in the 100-hour, high-flux capsule will be checked and further evaluated by comparing them with similar measurements obtained during the present measuring interval, with the a-c ground connected.

Neutron and Gamma Exposures

The integrated fast neutron flux during the irradiation of the 100-hour, high-flux capsule was measured with nickel dosimeter wires attached to the test assembly at five positions, one at the center and four at 90-degree intervals on the periphery of the test assembly. After the termination of the irradiation, the nickel wires were removed and analyzed to determine the integrated fast neutron threshold fluxes. These threshold values were converted to total fast neutron fluxes (above 0.1 Mev) by the relation of nickel threshold flux to total fast neutron flux, established by the fast neutron spectrum data obtained during the mock-up dosimetry. The fast neutron flux above 0.1 Mev was determined from those mock-up data as the total neutron flux monitored by the Pu^{239} (n, f) reaction corrected for the activation contribution of resonance neutrons. This correction is explained in the Nuclear Dosimetry section of the report of May 15, 1963 (Supplement to the First Quarterly Report).

The gamma doses received by the specimens were calculated from the dose-rate measurements made in the high-flux nuclear mock-up and the irradiation time of 100 hours.

Resonance neutron exposures for the specimens were obtained in terms of the spectral function parameter ϕ_o, and the irradiation time T, by multiplying the total fast neutron fluxes by the ratios of ϕ_o to total fast neutron flux obtained from the mock-up measurements. The time-integrated resonance neutron fluxes for a given energy interval between 0.4 ev and 0.1 Mev can be found from values of $\phi_o T$ listed in Table 2 and integration of the following integral:

$$\phi_o T \quad \frac{dE}{E} \quad .$$

Radiation exposures for the individual specimen types are listed in Table 2. These values of the neutron and gamma exposures are averages determined from various dosimeter positions chosen in accordance with the location of each specimen type in the test assembly. The neutron exposures are presented in three groups:

Group I is the time-integrated total fast neutron flux (above 0.1 Mev).

Group II is the time-integrated flux above the nickel threshold (above 2.5 Mev). The differences between Groups I and II yield the specimen exposures in the 0.1 to 2.5 Mev energy range.

Group III is the product of the resonance spectral function parameter and the irradiation time ($\phi_o T$) to be used for computing resonance neutron fluxes. The resonance neutron energy region extends from approximately 0.4 ev to 0.1 Mev.

The fission plate power was monitored continuously during the 100 hours of irradiation by means of a fission chamber and a strip chart recorder which followed the output current of the chamber. The maximum variation of the fission plate power throughout the irradiation period was ±5 per cent.

The gamma dose rates were measured in the nuclear mock-up before and after the specimen irradiation. A 4 per cent decrease in the dose rate occurred during the irradiation because of decay of the spent fuel elements. The gamma dose values listed in Table 2 result from the average dose rates during the 100-hour experiment.

The radiation exposures are higher than anticipated. This is probably due to a slight error in the positioning of the test facility which placed the upper portion of the test region closer to the fission plate than the position of the mock-up. This resulted in a neutron flux in the upper portion that was higher than expected, and raised the volume average above the desired value.

TABLE 2. RADIATION EXPOSURES FOR INDIVIDUAL SPECIMEN TYPES

Specimen Type	Group I 10^{13}n-cm^{-2}	Group II 10^{12}n-cm^{-2}	Group III 10^{11}n-cm^{-2}	Gamma Dose, 10^9 ergs g^{-1}(C)
Good-All 683G capacitors	1.03	3.75	1.40	0.98
Aerovox P3232N capacitors	1.64	5.96	1.50	0.75
General Electric capacitors	1.51	5.49	1.54	1.06
Fansteel HP capacitors	1.11	4.04	1.36	1.09
Sprague 118P capacitors	1.77	6.44	1.62	0.84
1N916 diodes	1.58	5.74	1.87	1.52
1N2063 rectifiers	1.76	6.40	1.83	1.30
PS4653 diodes	1.15	4.18	1.53	1.24
FD643 diodes	1.41	5.13	1.74	1.23
FD1184 diodes	1.47	5.34	1.77	1.57
1N822 diodes	2.52	9.16	2.13	0.96
3N58 silicon controlled switches	1.85	6.73	1.75	1.32
2N1132 transistors	1.27	4.62	1.55	1.09
2N2412 transistors	1.31	4.76	1.57	1.42
2N861 transistors	2.40	8.73	2.01	0.85
2N911 transistors	1.33	4.84	1.63	1.15
2N915 transistors	1.38	5.02	1.66	1.50
2N930 transistors	2.47	8.98	2.08	0.89
2N1050 transistors	1.38	5.02	1.69	1.19
2N2297 transistors	1.43	5.20	1.72	1.56
2N914 transistors	2.51	9.13	2.11	0.93
Allen-Bradley CB resistors	1.46	5.31	1.80	1.23
Corning Glass C-07 resistors	1.54	5.60	1.85	1.62
Texas Instruments CG resistors	2.64	9.60	2.22	0.87
Sigma 32RJD90GD relays	2.02	7.34	1.98	1.21
IHMI switches	1.24	4.51	1.62	1.51
SP-13 transformers	2.09	7.60	2.10	1.25
Bendix connectors	1.18	4.29	1.58	1.11
Cinch connectors	2.48	9.02	2.08	0.82
New England Instruments 78P potentiometers	1.80	6.54	1.78	1.30

The gamma doses received by the specimens are high because the fuel elements were so positioned as to yield the desired average dose rate over a greater volume of the test facility than was finally occupied by the specimens. The specimens were located through a region of peak gamma dose rates.

Instrumentation

The instrumentation capability for measuring leakage current and insulation resistance was improved by approximately one order of magnitude with a modification in the circuit design. This modification has reduced the stray leakage within the instrumentation and its connecting cables to 0.0001 microampere at 40 volts and to 0.0005 microampere at 200 volts. Measurements that include the leakage current of wire pairs between the instrumentation room and the barrier strip terminations near the pool, however, indicate an over-all current of approximately 0.007 microampere at 200 volts. A side result of the effort to improve the accuracy of measurements was the discovery of interaction between electronic parts mounted in different environmental units, through the loading circuits. The cause of this interaction was isolated to the 10,000-hour, 100 C low-flux capsule (Group III) and the environmental chamber for the control specimens under vacuum conditions (Group II).

Investigation as to the reasons for the interaction in the environmental chamber for the control specimens under vacuum conditions (Group II) resulted in the discovery of a number of electrical grounds which had occurred due to vibration from the forepump of the vacuum system. The major effect of this vibration was the grounding of the transistor cases, and therefore the collector terminals, to the aluminum plates on which they are mounted. These grounds have been eliminated and the forepumps are being vibration isolated in all four vacuum systems to prevent the reoccurrence of this problem in the future.

The interaction in the 10,000-hour, 100 C, low-flux capsule (Group III) was thought to be due to the same problem. However, when the capsule assembly was removed from the shielding pool and dismantled, a water leak was discovered on the atmosphere side of the vacuum plate containing the electrical feedthroughs for the lead wires to the test specimens. The water and associated corrosion caused electrical shorts and grounds and produced effects similar to those which occurred in the environmental chamber for the control specimens under vacuum conditions (Group II). The leak, which occurred at the O-ring seal, has been corrected, and the connectors and electrical feedthroughs have been cleaned to where electrical measurements indicate they are satisfactory as to insulating properties and low-resistance contacts.

Measurement Status of Test Groups I, II, and V

Initial measurements at room ambient temperature have been completed on Test Groups I, II, and V with the exception of measurements on the five capacitor types, the 2N2297 transistors, and four diode types (FD1184, 1N2063, 1N822, and PS4653). These measurements and initial measurements at each group's test ambient will be completed during the next report interim.

Measurement Status of Test Group III

Parameter measurements on the component parts in Test Group III (100 C, 10,000-hour low-flux capsule) have been delayed due to the time required to remove the capsule assembly from the shielding pool and to correct the water leak and the damage it caused to the connectors and electrical feedthroughs. However, it is expected that the initial measurements at both room ambient and test ambient will be completed during the next report period.

Cadmium Sulfide Cells

Twenty Type CL605 cadmium sulfide cells manufactured by Clairex were irradiated in the cobalt-60 gamma source. The exposure rate was $1.04 \pm 0.008 \times 10^6$ ergs g^{-1} (C) hr^{-1}. This is a factor of 100 greater than expected from a nuclear auxiliary power system.

The cadmium sulfide cells were mounted in two horizontal straight rows of 10 each in a watertight, lighttight container. The container was equipped with a constant light source consisting of a Type Q500T3/CL-120V Quartzline lamp manufactured by General Electric. The lamp was mounted in a horizontal position, above and parallel to the two rows of test specimens, with lead shielding to protect it from the radiation. The intensity of the light source was approximately 400 foot-candles.

Results from the 1000-hour gamma irradiation of the CL605 cadmium sulfide cells are shown in Figures 1 through 5. The curves are plotted without consideration of the four measurement periods from 100 to 400 hours, inclusive. The decrease in the measurements at these intervals is believed to be due to degradation in the cell used to monitor the light source or in some unknown degradation of the source. This is indicated by the parameter values shown at 500 hours and thereafter which were measured after the original Type Q500T3/CL-120V Quartzline lamp was replaced following the 400-hour measurements.

The cell voltage distributions as a function of radiation exposure shown in Figures 1 and 2 indicate a slight but general decrease in this parameter with length of exposure. Similar graphs of the cell resistance, Figures 3 and 4, show a somewhat pronounced degradation in cell resistance under dim illumination, with a decrease of approximately 50 per cent between the initial and 500-hour measurements. However, the CL605 cadmium sulfide cells were still highly sensitive to light, as shown in Figure 5 which indicates that bright illumination decreases the cell resistance to less than 10 per cent of the value measured with dim illumination.

CLH/DJH/ENW:eh

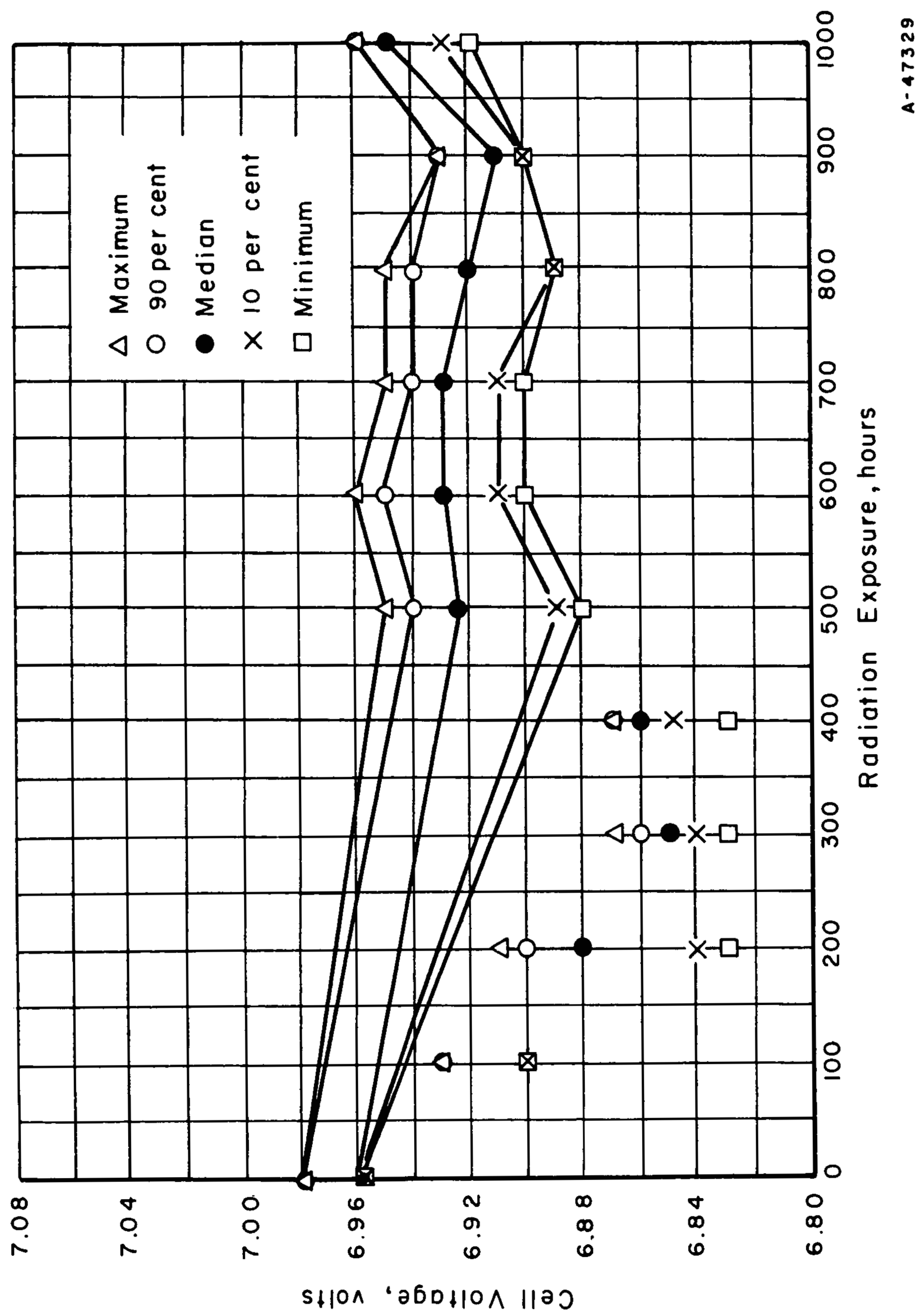

FIGURE 1. DISTRIBUTION OF CELL VOLTAGE AS A FUNCTION OF RADIATION EXPOSURE WITH DIM ILLUMINATION

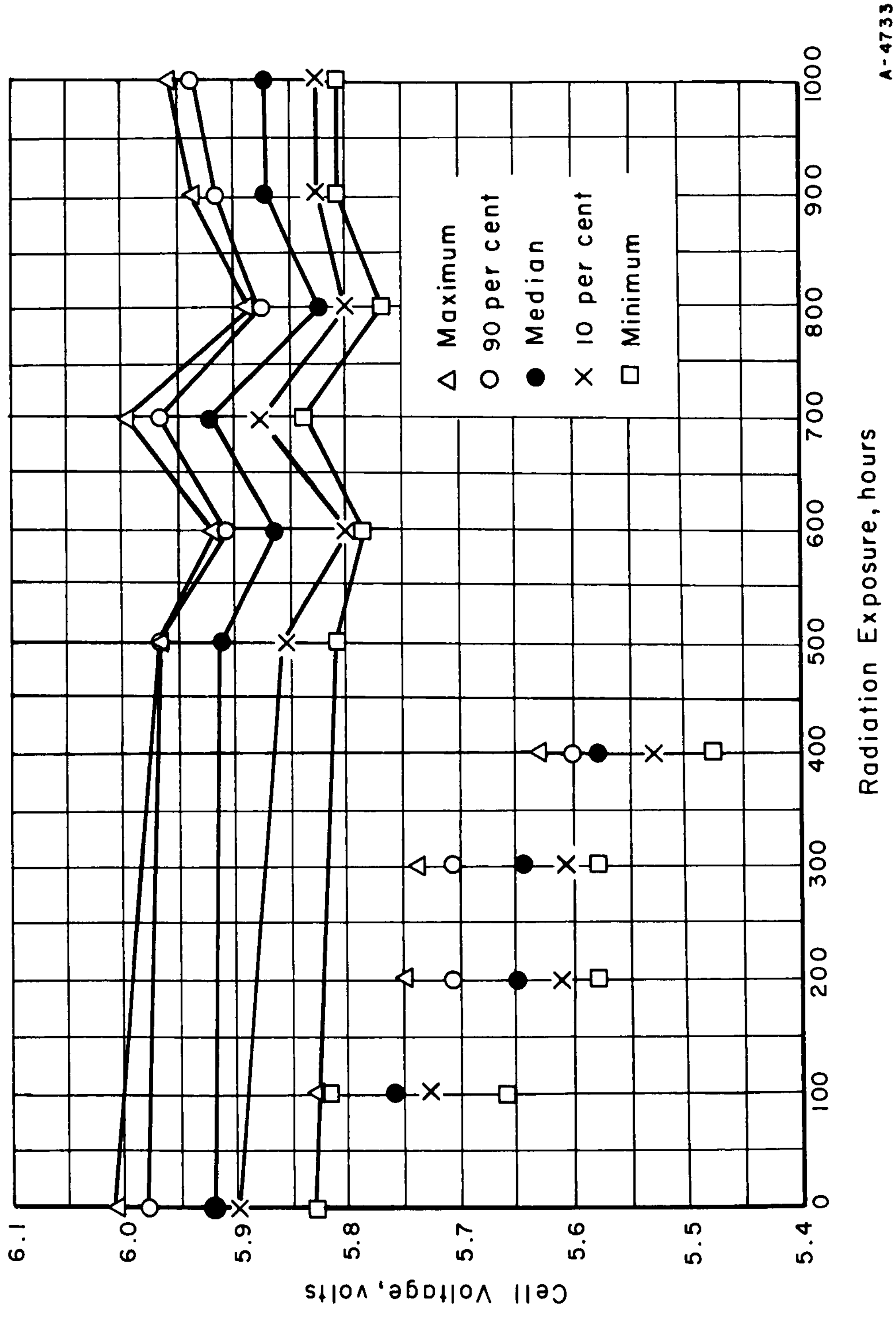

FIGURE 2. DISTRIBUTION OF CELL VOLTAGE AS A FUNCTION OF RADIATION EXPOSURE WITH BRIGHT ILLUMINATION (APPROXIMATELY 400 FOOT-CANDLES)

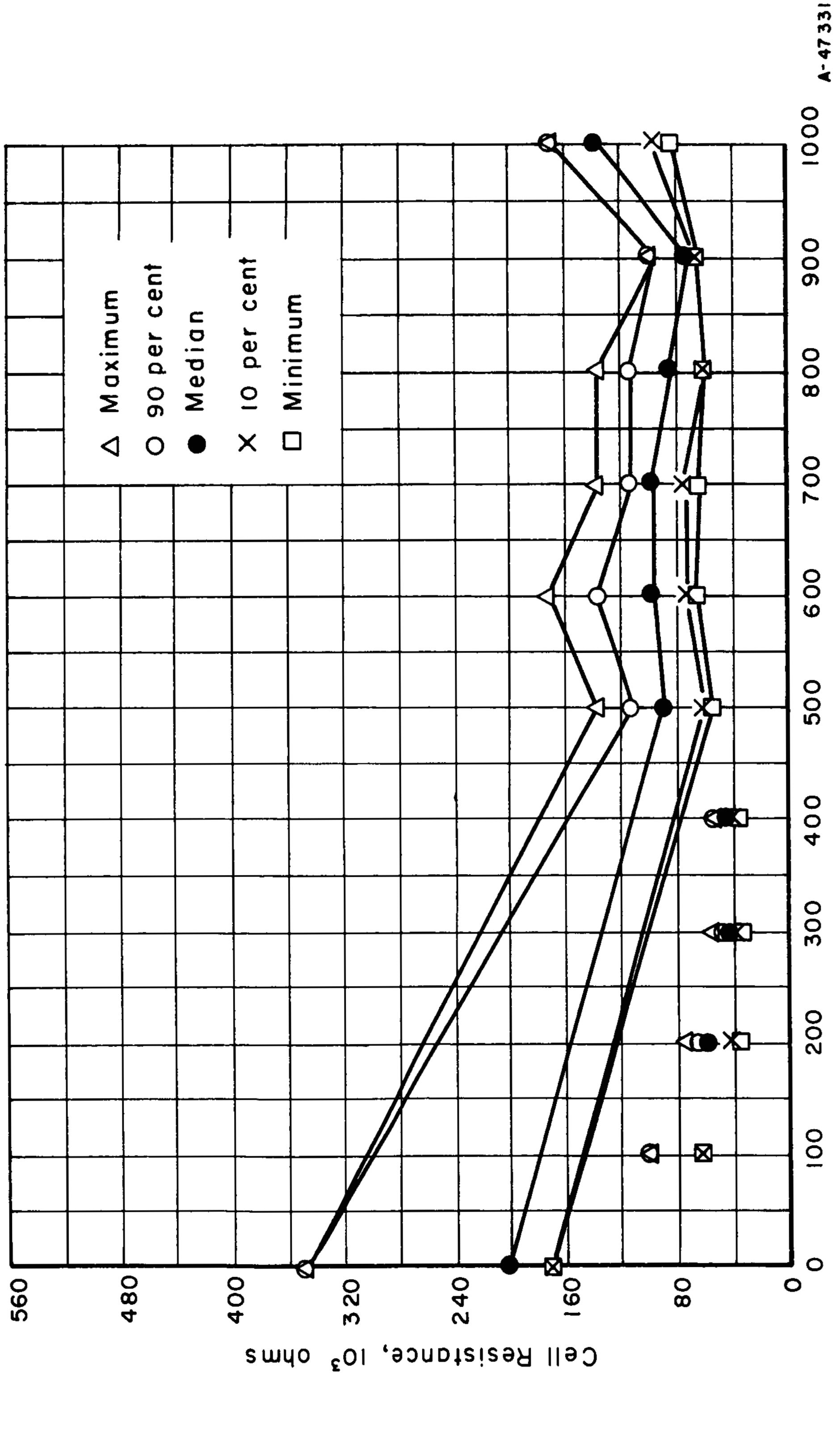

FIGURE 3. DISTRIBUTION OF CELL RESISTANCE AS A FUNCTION OF RADIATION EXPOSURE WITH DIM ILLUMINATION

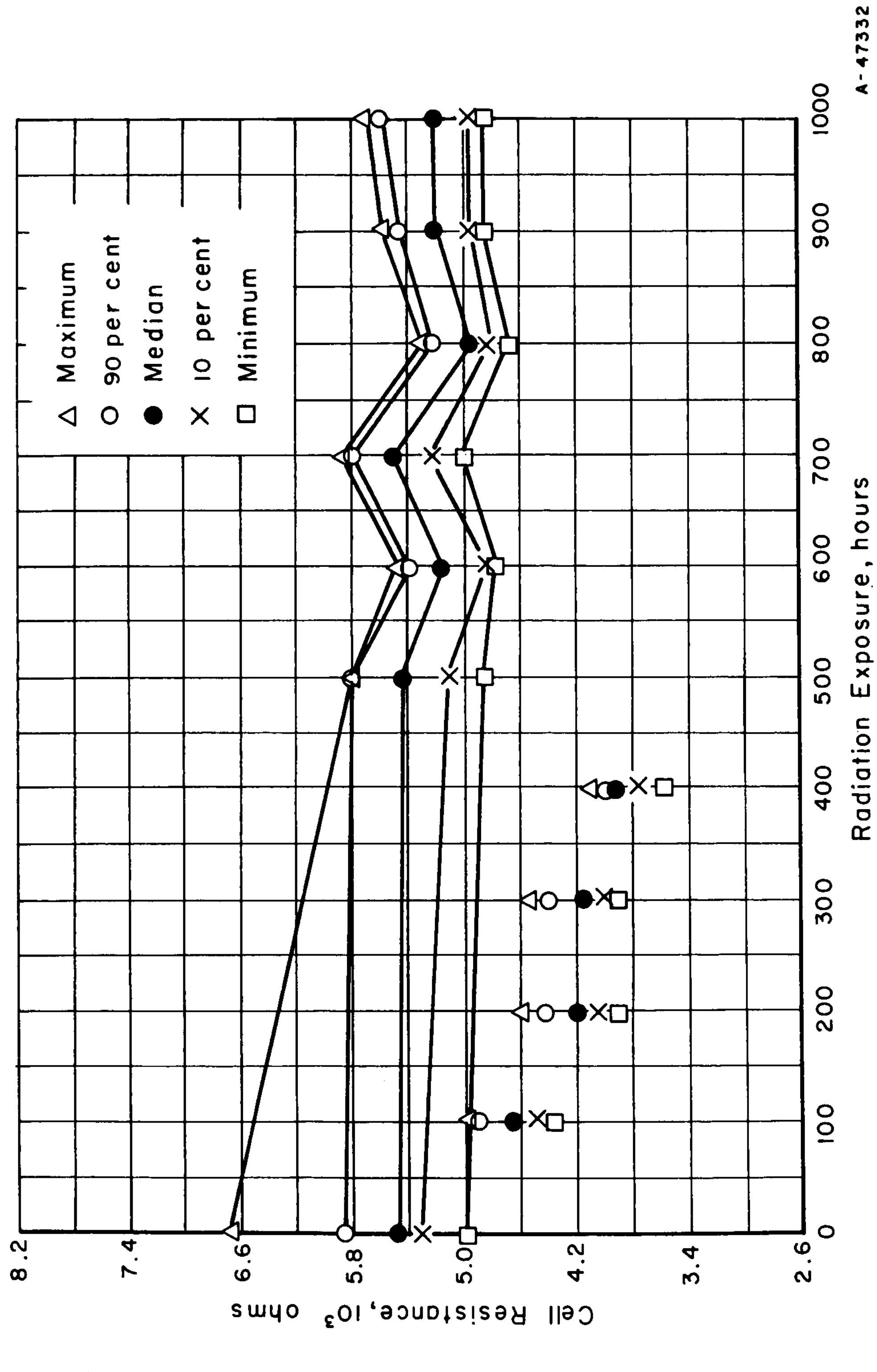

FIGURE 4. DISTRIBUTION OF CELL RESISTANCE AS A FUNCTION OF RADIATION EXPOSURE WITH BRIGHT ILLUMINATION (APPROXIMATELY 400 FOOT-CANDLES)

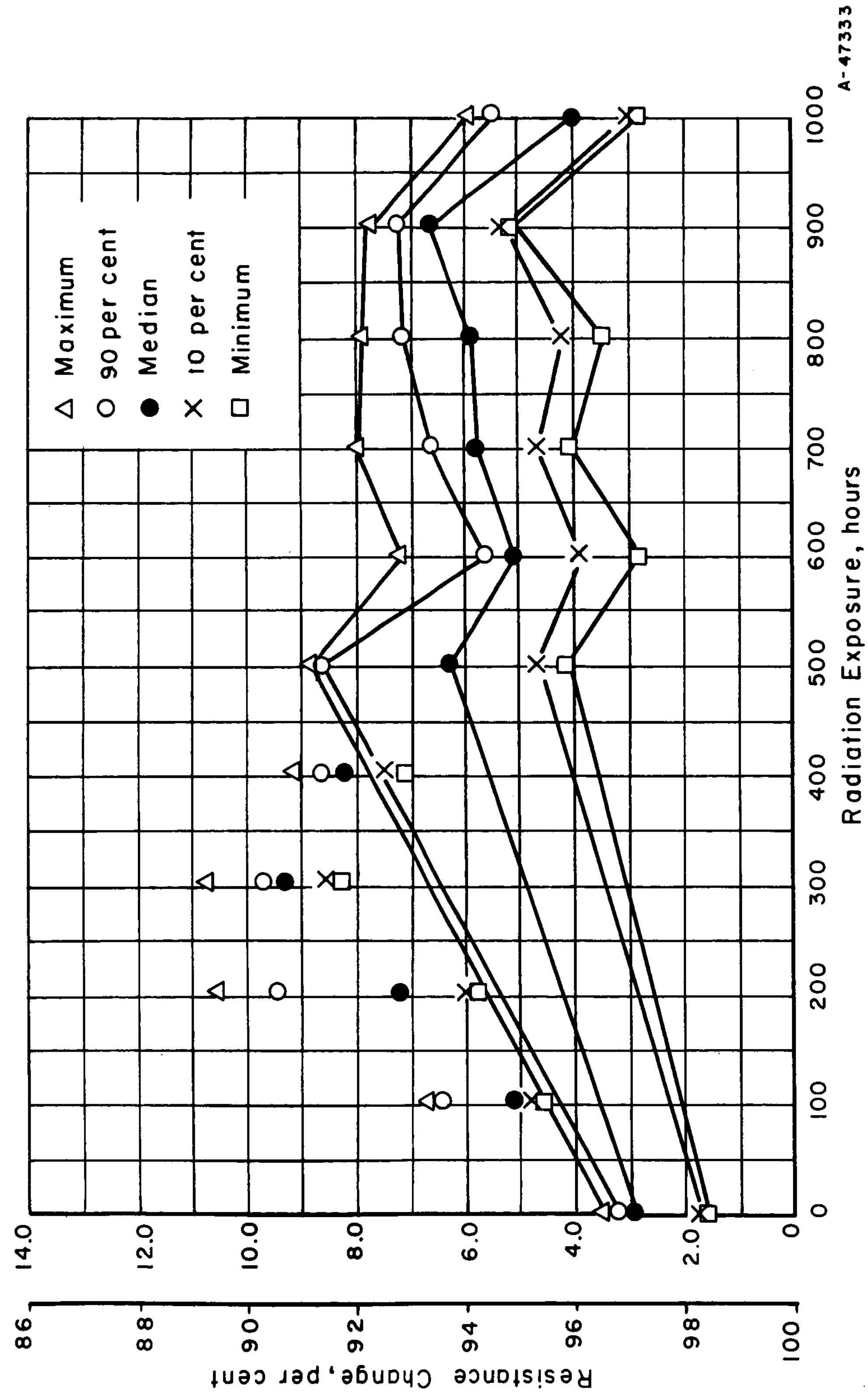

FIGURE 5. DISTRIBUTION OF THE RATIO OF CELL RESISTANCE (R_B/R_D) AND PER CENT CHANGE IN CELL RESISTANCE WITH BRIGHT AND DIM ILLUMINATION AS A FUNCTION OF RADIATION EXPOSURE